David M. Bevly

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Department of Mechanical Engineering
Auburn University
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Education

Stanford University **Stanford, CA**
Ph.D., Mechanical Engineering, September 2001. Thesis directed by Professor Bradford Parkinson entitled "High Speed, Dead Reckoning, and Towed Implement Control for Automatically Steered Farm Tractors Using GPS."
Major Area: Automatic Control Minor Area: Mechatronic Systems

Massachusetts Institute of Technology **Cambridge, MA**
Master of Science, Mechanical Engineering, September 1997. Thesis directed by Professor Steven Dubowsky, entitled "Action Module Planning and Cartesian Based Control of an Experimental Climbing Robot."

Texas A&M University **College Station, TX**
Bachelor of Science, Mechanical Engineering, Summa Cum Laude, May 1995. Broad curriculum in mechanical engineering with emphasis in design, dynamics, and control. Completed undergraduate research units directed by Professor Christian Burger.

Awards

2000 SAE Myers Award for Outstanding Student Paper
Best Paper of Session: ION GPS 2000
Best Presentation of Session: ACC 2000
Stanford Mechanical Engineering. 3-D Doctoral Fellowship
MIT Starr Foundation Fellowship recipient
Research Careers for Minority Scholar (RCMS) recipient
Texas A&M Presidential Achievement Award

Research Background

GPS Lab, Stanford **Stanford, CA**
Graduate Researcher *1998-2001*
Performed research and implementation of hardware for automated control of a farm tractor using GPS. Developed accurate vehicle models for high-speed control and towed implement control. Responsible for programming data acquisition equipment for Lynx Real Time Operating System and integration of several analog sensors. Developed method for integrating multiple inertial type sensors with GPS, through an EKF, for estimating multiple biases and dead reckoning control of the tractor. Created computer simulations and models to verify control and estimation techniques performed on the tractor.

DYNAMIC Design Lab, Stanford **Stanford, CA**
Graduate Researcher *1999-2001*
Initiated the ideas and performed research on the use of GPS velocity measurements for estimation of vehicle states and developed a method for measuring wheel slip and side-slip angle. Developed vehicle simulation models and performed experiments on a test vehicle to verify methodology.

Field and Space Robotics Laboratory, MIT **Cambridge, MA**
Graduate Researcher *1995-1997*
Performed research and experimentation of planning and control techniques on an experimental climbing robot. Developed a simplified computed torque control technique for mobile robots and verified the algorithm on the climbing robot. Modified an action module planning technique to incorporate specifics of the climbing robot for verification of the planning methodology. Created computer simulations for a graphical interface to study the system. Performed research and hands-on design of modular field robotic systems. Responsible for electrical and mechanical hardware, as well as software to interface between experimental systems, sensors, and computer hardware.

Texas A&M University **College Station, TX**
Undergraduate Research Assistant *1994-1995*
Testing of wear and galling resistance on different surfaces for a power screw in a high pressure choke valve for Cooper Industries, Oil Tool Division. Designed and performed experiments to determine wear properties of different surface treatments.

Teaching Experience

Auburn University **Auburn, AL**
MECH 4420 – Vehicle Dynamics *2002-present*
Developed this new course as part of the College of Engineering's Automotive Certificate Program. Emphasized the importance of computational numerical methods to simulate and analyze vehicle systems.
MECH 3140 – System Dynamics and Controls *2001-present*
Taught this traditional undergraduate course. Assigned homework and design projects requiring simulation, analysis, and design of a control system using MATLAB.

Stanford University **Stanford, CA**
E207B Modern Control II Teaching Assistant *Spring 2000*
Developed all of the class homework sets, labs, final project, as well as all of the solution sets for this graduate level class. Gave 5 of 19 class lectures, including lectures on stochastic systems, system identification, and extended Kalman filtering. Gave a weekly televised help session lecture. Student evaluation rating of 4.5/5.0. Received positive remarks from a lecture evaluation performed by the Stanford Center for Teaching and Learning (evaluation available upon request).
ME 218 Smart Product Design (Mechatronics) Coach *1998-2001*
Involved in development of course projects, supervising laboratory exercises, and mentoring group projects.

Work Experience

Auburn University **Auburn, AL**
Assistant Professor, Department of Mechanical Engineering *2001 – present*
In charge of teaching mechanical engineering courses and developing a strong externally funded research program in the area of dynamics, controls, and transportation systems.

Veteran Affairs Hospital **Palo Alto, CA**
Rehabilitation R&D Department *1998 – 2000*
Contract control engineer in charge of system identification and control of a motor controlled rehabilitation bicycle. Performed experiments to identify model parameters of the bicycle. Developed an impedance based control architecture for use in rehabilitating patients.

Sanden International (U.S.A.), Inc **Wylie, TX**
Production Engineering Department *Summer 1994 & Summer 1995*
Implemented an automated system including PLC programming. Designed a set of fixtures to improve manufacturing process on an assembly line. Maintained and designed other improvements on an assembly line.
Quality Assurance Department *Fall 1993*
Performed process capability studies. Wrote inspection standards and procedures. Became familiar with manufacturing sampling procedures, measurement processes, and tools, including a coordinate measuring machine.

E.I. DuPont de Nemours **Victoria, TX**
Production Engineering Department *Fall 1992*
Completed several change of design packages to maintain the refinery. Sized an orifice, steam separators, relief valves, and pumps for improved plant operation. Involved in all aspects of design packages from problem and solution to design and implementation.

Publications

Bevly, D. M., "GPS: A Low Cost Velocity Sensor for Correcting Inertial Sensor Errors on Ground Vehicles," *Journal of Dynamic Systems, Measurement, and Control*, June 2004.

Daily, R., Bevly, D. M., "The Use of GPS for Vehicle Stability Control Systems," *IEEE Transactions on Industrial Electronics*, Vol. 51, No. 2, April 2004.

Bevly, D. M., Ryu, J., Sheridan, R., Gerdes, J. C, "Integrating INS Sensors with GPS Velocity Measurements for Continuous Estimation of Vehicle Side-Slip and Tire Cornering Stiffness," submitted to *IEEE Transactions on Intelligent Transportation Systems*.

Bevly, D.M., Gerdes, J.C., Parkinson, B., "A New Yaw Dynamic Model for Improved High Speed Control of a Farm Tractor," *Journal of Dynamic System Measurement and Control*, Vol. 124, No. 4, December 2002, pp. 659-667.

Bevly, D.M., Gerdes, J.C., Wilson, C., "The Use of GPS Based Velocity Measurements for Measuring Side Slip and Wheel Slip," *Vehicle System Dynamics*, Vol. 38, No. 2, August 2002, pp. 127-147.

Bevly, D. M., Rekow, A., Parkinson, B., "Comparison of an INS vs. Carrier Phase DGPS Attitude in the Control of Off-Road Vehicles," *Journal of Navigation*, Vol. 42, No. 4, Winter 2000.

Bevly, D. M., Dubowsky, D., Mavroidis, C, "A Simplified Cartesian Computed Torque Controller and its Application to an Experimental Climbing Robot," *Journal of Dynamic Systems, Measurement and Control*, Vol. 122, No. 1, March 2000, pp. 27-32.

Rekow, Bell, Bevly, Parkinson, "System Identification and Adaptive Steering of Tractors Utilizing Differential Global Positioning System", *AIAA Journal of Guidance, Control, and Dynamics*, Vol. 22, No. 5, September 1999, pp.671-674.

Bevly, D. M., Gerdes, J. C., Parkinson, B., "Yaw Dynamic Modeling for Improved High Speed Control of a Farm Tractor," *Proceedings of the 2000 ASME IMECE*, Orlando, FL.

Bevly, D. M., Rekow, A., Parkinson, B., "Evaluation of a Blended Dead-Reckoning and Carrier Phase Differential GPS System for control of an Off-Road Vehicle," *Proceedings of the 1999 ION-GPS Meeting*, Nashville, TN, September 1999 (being revised for journal submission).

Bevly, D.M., Parkinson, B.W., "Cascaded/Separate Filters for Accurate Estimation of Multiple Biases, Dead-Reckoning, and Full State Feedback," *in progress for journal submission.*

Bevly, D. M., Sheridan, R., Gerdes, J. C, "Integrating INS Sensors with GPS Velocity Measurements for Continuous Estimation of Vehicle Side-Slip and Tire Cornering Stiffness," *Proceedings of the 2001 American Control Conference*, June 2001.

Bevly, D.M., Parkinson, B.W., "Carrier-Phase Differential GPS for Control of a Tractor Towed Implement," *Proceedings of the 2000 ION-GPS Meeting*, Salt Lake City, Utah, September 2000 (best paper of session award).

Bevly, D. M., et. al., "The Use of GPS Based Velocity Measurements for Improved Vehicle State Estimation," *Proceedings of the 2000 American Control Conference*, June 2000, Chicago, IL.

Bevly, D. M., Farritor, S., Dubowsky, S., "Action Module Planning and its Application to an Experimental Climbing Robot," *Proceedings of the IEEE International Conference on Robotics and Automation*, Sept. 2000, San Francisco, CA.

Bevly, D.M., Rekow, A., Parkinson, B., "Incorporating INS with Carrier-Phase Differential GPS for Automatic Steering Control of a Farm Tractor," Presented at the 1999 SAE Intl. Off-Highway and Powerplant Congress & Exposition, Indianapolis, IN, September 1999, Reprinted in *Agricultural Machinery, Tires, Tracks, and Traction (SP-1472)*, Paper No. 1999-01-2851 (received the 2000 SAE Myers Award for Outstanding Student Paper).

Bevly, D. M., Rekow, A., Parkinson, B., "Comparison of an INS vs. Carrier Phase DGPS Attitude in the Control of Off-Road Vehicles," Proceedings of the 1999 ION Annual Meeting, Cambridge, MA, June 1999.

Research Interests

The GPS Vehicle Dynamics Laboratory focuses on the robust control of autonomous vehicles using GPS and Inertial Navigation System (INS) sensors. Our research has three main thrusts: sensor fusion/integration, on-line system identification, and adaptive control techniques and their application to vehicle dynamics and transportation. These methods can be used for such things as determining vehicle and driver models. Improved driver models could be used by a number of vehicle monitoring systems, i.e. safety systems that determine the effectiveness of a driver and increase road safety by removing fatigued or intoxicated drivers from the road. Vehicle modeling and state estimation is important in a number of current vehicle safety systems, such as ABS, traction control, and stability control. Additionally, future vehicle safety systems, such as driver assisted systems, adaptive cruise control, and even full autonomous lane-keeping, require precise vehicle models.

The first part of our research is to investigate methods for better calibration of the INS errors while GPS measurements are available. This will improve performance of the INS unit during periods when the GPS signal is obstructed (as well as between GPS measurements). Improved performance will be sought by including dynamic models of the vehicle system and incorporating these dynamic constraints with low-level INS/GPS measurements. Carrier-phase GPS signals, in conjunction with the system model, will be used to accurately calibrate the INS model and its errors. This precise calibration will provide a dead reckoning system, initialized using GPS, capable of providing accurate estimates of the vehicle states (position and attitude) for the continuous control of the vehicle during GPS outages. The integration of INS and GPS can be used to provide an unbiased, high-update estimate of vehicle states such as position, velocity, and attitude. This blended solution thereby provides accurate data for modeling autonomous vehicles. The ability to accurately determine the vehicle states as well as the vehicle model on-line, during changing environments, will in turn lead to an increase in the control performance of a vehicle.

Finally, our research focuses on adaptive control and estimation algorithms for autonomous vehicles. On-line system identification techniques capture the changing parameters of the systems, which can be used to adapt the control and estimation algorithms. Once techniques for using the GPS/INS solution to perform on-line identification have been developed, methods that adapt, or self-tune, optimal controllers and estimators (such as LQR and Kalman filters) can be investigated. The adaptation of the control and estimation algorithms to the continually identified model parameters will lead to accurate and robust performance of these autonomous systems.

Auburn University GPS Vehicle Dynamics Laboratory

The GPS Vehicle Dynamics Laboratory focuses on the control and navigation of vehicles using GPS in conjunction with other sensors, such as Inertial Navigation System (INS) sensors. The laboratory has several research thrusts including: sensor fusion/integration, on-line system identification, adaptive and robust control algorithms, and vehicle state and parameter estimation. These research thrusts are focused towards vehicle dynamics and transportation, including heavy trucks, passenger cars, off-road vehicles, as well as autonomous and unmanned vehicles. The laboratory consists of various GPS receivers (including a software GPS receiver), Inertial Measurement Units (IMUs), an instrumented Chevrolet Blazer, an automatically steered John Deere tractor, and access to an iRobot ATRV. Current projects include ultra-tight GPS/INS coupling (sponsored by the Army), study of vehicle rollover propensity, improved steering control of GPS guided farm tractors (sponsored by John Deere), vehicle and driver monitoring, and navigation and control of unmanned ground vehicles (UGVs).

As part of a current project with U.S. Army Aviation and Missile Command, a GPS receiver capable of performing ultra-tight GPS/INS integration has been acquired. Ultra-tight GPS/INS coupling provides improved anti-jamming resistance, improved satellite tracking, as well as allows for immediate GPS signal reacquisition after short GPS outages. This GPS unit could be valuable in investigating GPS navigation in cluttered environments, where GPS satellite signals become unavailable and available for intermittent periods. The GPS Vehicle Dynamics Laboratory also has access to the National Center for Asphalt Testing (NCAT) test track (http://www.pavetrack.com/). Validation of navigation and parameter and state estimation algorithms can be performed using the vehicles on the NCAT track. GPS and inertial sensors can be mounted on the semi-trucks or our own test vehicles to validate proposed estimation and control algorithms. Additionally, errors such as jamming, multi-path, and other sensor errors can be simulated to test the algorithms ability to reject these disturbances and continue to provide an accurate navigation solution.

GPS Vehicle Dynamics Laboratory
List of Research Interests

- Robust Control algorithms for computationally restricted platforms
  - Simple adaptive algorithms
  - Computationally efficient controllers

- Sensor noise canceling for system identification

- Low level GPS/INS integration for improved navigation
  - Improved dead reckoning through better initial alignment
  - Improved INS error characterization (including INS scale factor estimation)

- Model-free (human-like) driver Control algorithms for autonomous vehicles
  - Controllers that can be moved from one vehicle to another

- Multiple/Redundant sensor fusion for on-line system identification

- Low-level GPS/INS integration using vehicle dynamic constraints for improved vehicle state and parameter estimation

- Two-step on-line parameter identification of non-linear systems in the presence of noise

- Design and control of MEMS actuators

- Control of low-flying UAVs for mine recovery (and forest pesticide delivery)

- Sensor and system fault detection and reconfigurable control and estimation algorithms

- Low-cost MEMS sensor integration with GPS for UGVs and UAVs

Auburn GaVLab Facilities and Equipment

- ## NCAT Test Track

The GPS Vehicle Dynamics Laboratory has access to the National Center for Asphalt Testing (NCAT) test track (http://www.pavetrack.com/). The 1.7-mile oval track has four trucks driving on the track 16 hours a day (each driver performing an 8 hour driving shifts) and is broken into 200-foot sections of different pavement types. Detailed information on each section of the track is monitored including rut depth and coefficient of friction. Eight-hour driver shifts, changing rut depths, and detailed tire logging make the facility an ideal location for testing the algorithms developed in the area of intelligent transportation systems. GPS and inertial sensors can be mounted on the semi-trucks or our own test vehicles to validate proposed navigation and parameter and state estimation algorithms. Additionally, errors such as jamming, multi-path, and other sensor errors can be simulated to test the algorithms ability to reject these disturbances and continue to provide an accurate navigation solution.

- ## Automatically Steered John Deere Tractor

John Deere has loaned an 8420 auto-steer tractor (valued at $160,000) as a research platform for a funded research project with the company. The test tractor is located 20 miles from Auburn University and provides the ability to test various autonomous steering control strategies. Research will be conducted to quantify the variations in the dynamic steering model due to variations in vehicle configurations as well as variations in ground conditions.

- ## Instrumented SUV

Auburn has a fully instrumented Chevrolet Blazer that is used to run experiments at the NCAT test track. Like the tractor, this vehicle is used as a test-bed to validate newly developed algorithms in navigation and state and parameter estimation at highway speeds. Accurate dynamic models of the SUV are available in order compare simulated and measured vehicle responses.

- ## GPS Software Receiver

As part of a current project with U.S. Army Aviation and Missile Command, a GPS receiver capable of performing ultra-tight GPS/INS integration has been acquired. Ultra-tight GPS/INS coupling provides improved anti-jamming resistance, improved satellite tracking, as well as allows for immediate GPS signal reacquisition after short GPS outages. This GPS unit could be valuable in investigating GPS navigation in cluttered environments, where GPS satellite signals become unavailable and available for intermittent periods.

- ## Autonomous ATV

Sciautonics has loaned Auburn University their DARPA Grand Challenge Vehicle for the summer. Auburn was responsible for developing the speed and steering control for the vehicle as well as the GPS/INS navigation system for the vehicle in the 2004 Grand Challenge Race. The vehicle is equipped with a camera, Lidar, Starfire GPS receiver, IMU, wheel speed sensors and is fully autonomous (full x-by-wire capabilities). Auburn will use the vehicle to develop models (both on-road and off-road) and robust control algorithms for the next Grand Challenge Race.